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The Large Area Pulsed Solar Simulator (LAPSS)

R. L. Mueller

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16. Abstract

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Abstract

A Large Area Pulsed Solar Simulator (LAPSS) has been installed at JPL. It is primarily intended to be used to illuminate and measure the electrical performance of photovoltaic devices. The simulator, originally manufactured by Spectrolab, Sylmar, Calif., occupies an area measuring about 3 meters wide by 12 meters long. The data acquisition and data processing subsystems have been modernized. Tests on the LAPSS performance resulted in better than ±2% uniformity of irradiance at the test plane and better than ±0.3% measurement repeatability after warm-up. Glass absorption filters are used to reduce the level of ultraviolet light emitted from the Xenon flash lamps. This provides a close match to standard airmass zero and airmass 1.5 spectral irradiance distributions. The 2 millisecond light pulse prevents heatings of the device under test, resulting in more reliable temperature measurements. Overall, excellent electrical performance measurements have been made of many different types and sizes of photovoltaic devices.

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THE LARGE AREA PULSED SOLAR SIMULATOR

Introduction

The large area pulsed solar simulator (LAPSS) is now operational at JPL. It is primarily designed to illuminate and measure the electrical performance of photovoltaic devices with areas ranging from 1 cm^2 to 4.5 $meters^2$, and it is also useful for investigating other types of light-sensitive devices. The LAPSS is an excellent, close-spectral-matched light source for obtaining accurate electrical performance measurements on all types of single-junction photovoltaic devices. Because of the close spectral match and lack of intense spectral lines or absorption bands, reasonably accurate results are also obtained when using only this single light source for testing thin-film tandem-junction amorphous silicon devices.

LAPSS System Performance

The LAPSS produces a 2-millisecond light pulse from two Xenon flash lamps. Their intensity is adjustable over a wide range without altering the chosen standard spectral irradiance. The short duration of the light pulse prevents heating of the test cell/array, resulting in more-reliable temperature measurements and improved data accuracy. The LAPSS high-speed electronic load and data-acquisition system acquires a full current-voltage (I-V) characteristic curve during a single light pulse.

The uniformity of the irradiance at the test plane is ±2 percent over a 2.1 X 2.1 meter rectangular area, as shown in Figure 1. Repeated measurements over a period of several weeks show that measurement repeatability is better than ±0.3 percent after a thirty-minute warm-up time, but is no worse than ±1 percent without warm-up. This contributes to the highly accurate electrical performance measurements.

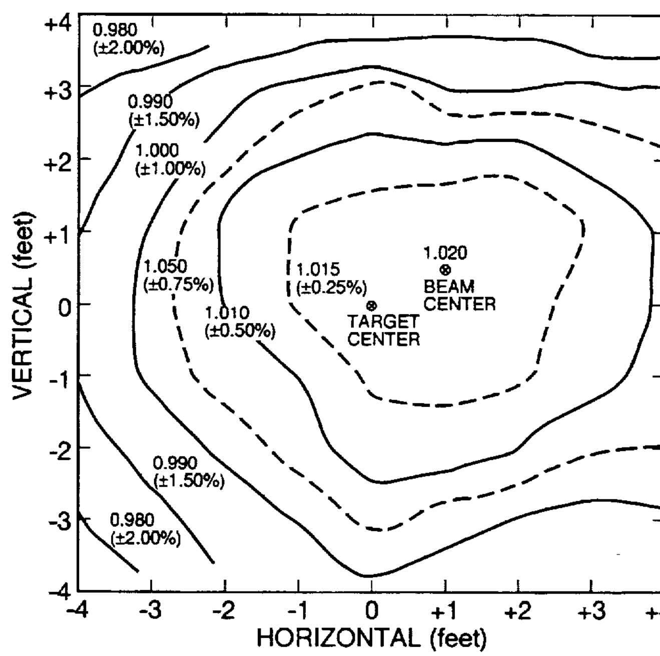

Figure 1. LAPSS Relative Uniformity of Intensity Contour Map.

Through the use of ultraviolet absorption filters and horizontal slit filters, the LAPSS can provide spectral irradiance distributions with a close spectral match to three different standard spectral irradiances, in accordance with References 1, 2 and 3. The standard spectral irradiances are the 136.7 mW/cm² airmass zero spectrum (AM0), the 100 mW/cm² normalized airmass 1.5 global spectrum (AM1.5G), and the 100 mW/cm² normalized airmass 1.5 direct spectrum (AM1.5D). The close match to these standard spectral irradiances is shown in Figures 2, 3 and 4. The LAPSS can also be used unfiltered if a substantially higher intensity is required at wavelengths between 300 and 400 nm. Typical results are shown in Figure 5.

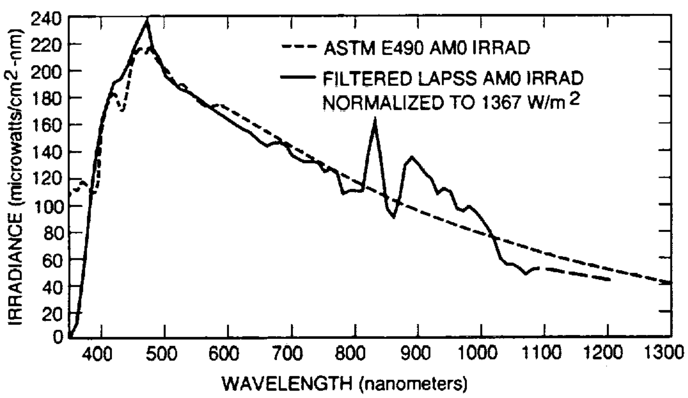

Figure 2. Spectral Irradiance (AM0, Filtered LAPSS vs ASTM).

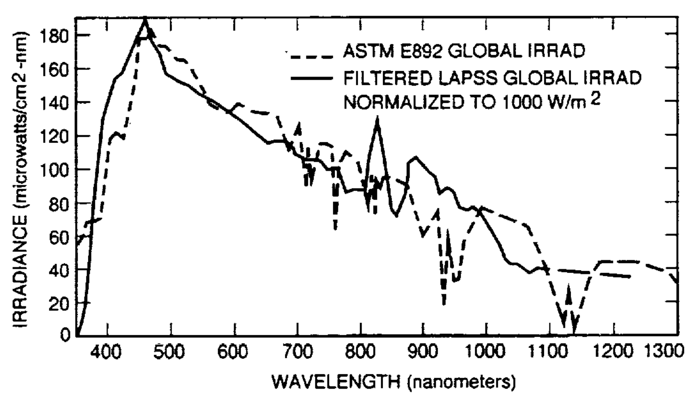

Figure 3. Spectral Irradiance (AM 1.5 Global, LAPSS vs ASTM).

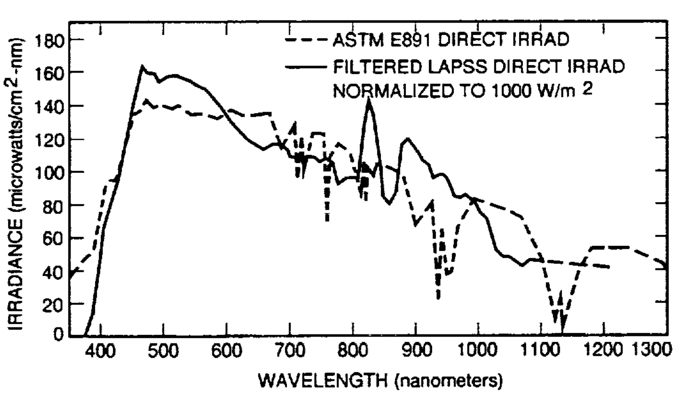

Figure 4. Spectral Irradiance (AM 1.5 Direct, LAPSS vs ASTM).

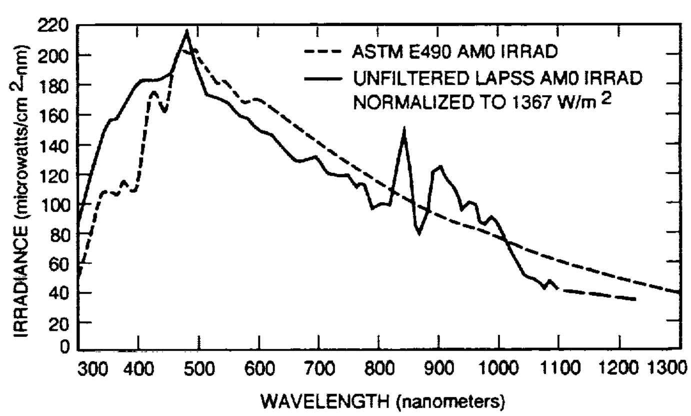

Figure 5. Spectral Irradiance (AM0, Unfiltered LAPSS vs ASTM).

LAPSS Capabilities

With the appropriate filtering in position, the LAPSS can be used for the low-cost, secondary calibration of reference solar cells or arrays in the standard irradiances without a strict requirement for matching spectral responses. As described in Reference 4, a comparison is made with a primary reference cell or balloon flight standard cell having a spectral response characteristic with only some similarity to that of the test cell/array. This method has shown excellent agreement with worldwide round-robin measurements, as described in Reference 5.

Since the LAPSS has an excellent spectral match to a choice of standard spectral irradiances, more-dependable current-temperature coefficients can be measured for those irradiances. Voltage-temperature coefficients can also be measured. These measurements can be obtained on reference cells, balloon-flight standard cells, or other photovoltaic devices with dimensions of 10 cm X 15 cm or less. The test cells are heat-sinked to a thermoelectric module, which is temperature-controllable from about 5° to 80° Celsius. A 30 cm X 30 cm thermoelectric module is also available for similar measurements on larger devices.

Solar cells and small arrays can also be characterized for their performance at different intensities while controlled to different temperatures within the previously mentioned range (5° to 80° Celsius). A number of slit filters are available for intensities of 5, 10, 15, 20, 25, 50, 60, 70, 80, 90, 100 and 136.7 mW/cm^2. This range of intensities is available at the standard (11 meters) lamp-to-target distance. Devices measuring 11 X 11 cm, or less, can be tested at a range of intensities nine times the above when moved to within 3.6 meters of the lamps.

Some photovoltaic devices, such as silicon solar cells with a back-surface field region, exhibit a large effective capacitance. This causes the resulting I-V characteristic curve to lag a few percent starting near the Maximum Power (P_{max}) of the device and continuing to a lesser and lesser degree up to the Open Circuit Voltage (V_{oc}) condition. This characteristic, which introduces an error, particularly in the power measurement, can be detected and corrected. Two methods have been incorporated into the JPL LAPSS. The first is the "Single-Point Mode 1," which essentially sets the electronic load at a constant load point instead of allowing it to sweep from I_{sc} to V_{oc} during the lamp flash. The second is simply making some measurements at fixed load resistances with the electronic load disabled. Both methods provide the same information by providing the device sufficient time to overcome the influence of the device's effective capacitance. A series of these measurements is made to obtain sufficient data to reveal the true shape of the I-V curve.

More-detailed information about the LAPSS subsystems, filters, and lamps is provided in the attached appendix.

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1. Anonymous, "Specification for Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables," ASTM E 490 American Society for Testing and Materials, Philadelphia, Pennsylvania (latest revision).

2. Anonymous, "Standard Terrestrial Solar Spectral Irradiance Tables at Air Mass 1.5 for a 37° Tilted Surface," ASTM E 892 American Society for Testing and Materials, Philadelphia, Pennsylvania (latest revision).

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4. R.L. Mueller, "Air Mass 1.5 Global and Direct Solar Simulation and Secondary Solar Cell Calibration Using a Filtered Large Area Pulsed Solar Simulator", Proc. 18th Photovoltaic Specialists Conf. (IEEE, Las Vegas, 1985), pp. 1698-1703.

5. H. Ossenbrink, R. Van Steenwinkel, and K. Krebs, "The Results of the 1984/1985 Round-Robin Calibration of Reference Solar Cells for the Summit Working Group on Technology, Growth and Employment," Commission of the European Communities, Directorate-General for Science Research and Development, Joint Research Centre, Ispra Establishment, April 1986. (Reprint EUR 10613 EN)

APPENDIX

Pulsed Illuminator Subsystem

The pulsed illuminator subsystem irradiates the test cell or array and a reference solar cell. Some test cells are shown in Figure 6. The primary components of this subsystem are the Pulse-Forming Network (PFN) and the Illuminator Assembly, which are shown in Figure 7.

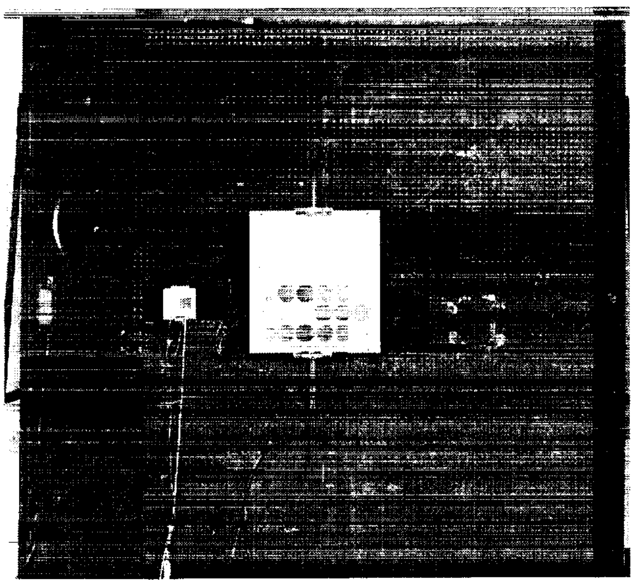

Figure 6. Solar array and reference cell mounted on 2.4 X 2.4 meter target area.

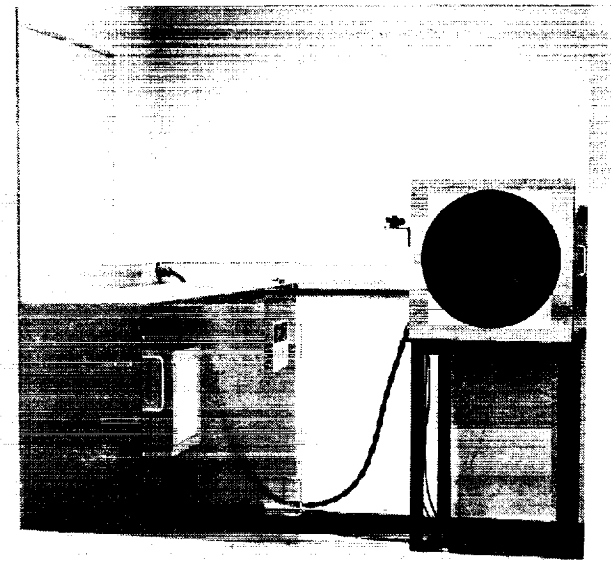

Figure 7. The Pulse-Forming Network (left) and the Illuminator Assembly (right).

The PFN is basically a high-voltage power supply capable of charging 2000 Mfd of storage capacitors up to 5000 volts in about 10 seconds. The charge voltage is presettable and is sensed with a built-in charge voltage sensor.

The Illuminator Assembly consists of two Xenon flash lamps, an RF lamp igniter, and baffling to constrain the light to the target plane. When the preset charge voltage is reached, the lamps are RF ignited, which causes the PFN capacitors to discharge through the lamps, via pulse-forming inductors.

The result is a sustained operation of the lamps for about 2 milliseconds, with the intensity varying about ±5 percent. The peak power to the lamps is over 7 megawatts with the standard charge voltage of 2700 volts, which is achieved after 7 seconds of capacitor charging.

The Data-Acquisition and -Processing Subsystem

The data-acquisition and -processing subsystem is synchronized with the illuminator subsystem and simultaneously measures the I-V performance characteristics of a test cell/array and a reference solar

cell. The primary components of the updated data-acquisition and -processing subsystem are the original LAPSS control console with a built-in high-speed electronic load, an ISAAC 2000 data-acquisition system with analog-to-digital converters, a Compaq Deskpro 286 personal computer (PC), an Epson FX-286 printer, and an X-Y plotter.

The LAPSS control console, which is shown in Figure 8, contains the majority of all system components for operating the LAPSS except for the ISAAC 2000, printer and plotter. The high-speed electronic load is primarily composed of eight power transistors. During the 2 milliseconds of sustained illumination, the high-speed electronic load is applied to the test cell/array, and is swept from a short-circuit to an open-circuit condition. Simultaneously, a short circuit is applied to an unloaded reference cell to obtain its I_{sc}, short-circuit current. (Note: There is also a provision for measuring the millivolt output of a balloon flight standard which has a built-in load resistor.)

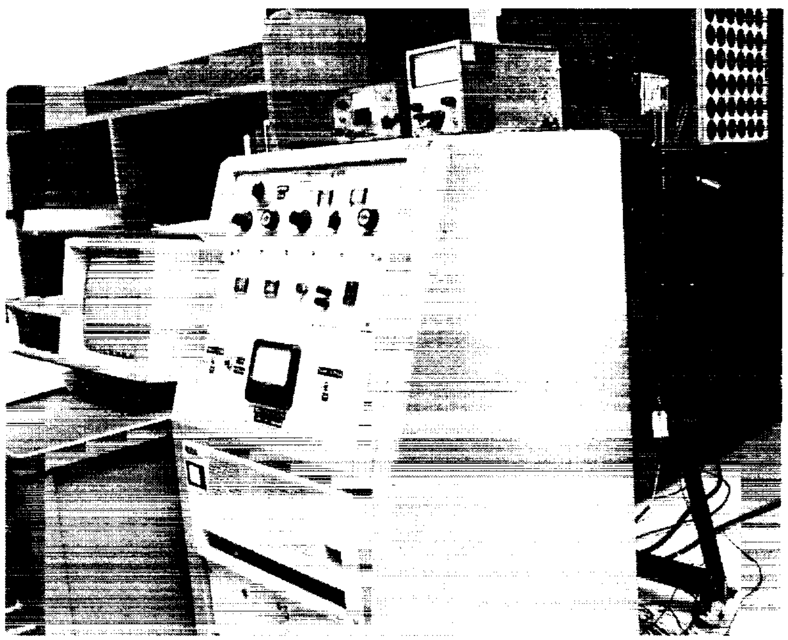

Figure 8. The LAPSS control console, with the Compaq Deskpro 286 PC and the target area.

At 15-microsecond intervals during the electronic load sweep, the test device voltage, and current, and the reference cell or balloon flight standard cell signal are simultaneously sampled by the ISAAC 2000. The analog data is sequentially converted to digital data and stored in the ISAAC 2000 memory.

At the conclusion of the sweep, the digital data is sent to the computer where it is corrected for lamp intensity variations. The data is then converted to engineering units of voltage and current. The resulting data is also corrected for any difference between the desired temperature and the actual operating temperature using standard or manually inputted temperature coefficients. The data is then listed on the PC monitor along with a summary of derived parameters, including

test cell/array I_{sc}, V_{oc}, P_{max}, I_{pmax}, V_{pmax}, Fill Factor and Efficiency. There is a provision for saving each set of data on the PC hard disk drive.

The identical data can also be sent to the printer in the same or a different format. If desired, this data can be averaged and then be printed in a concluding line. The X-Y plotter, soon to be installed, reconstructs an I-V characteristic curve from the tabular listing, and the derived parameters would be included as a part of the plot heading information.

Close-Matched Spectral Irradiance Options

Glass absorption filters used with the LAPSS have previously shown no notable change with time in their spectral characteristics, as described in Reference 4. Two different Schott™ glass absorption filters have been selected to reduce the level of ultraviolet light being emitted from the illuminator assembly. This is done to provide a closer match to desired spectral irradiance distribution. When the 136.7 mW/cm² airmass zero (AM0) spectrum or the 100 mW/cm² normalized airmass 1.5 global (AM1.5G) is required, a 1-millimeter thick Schott™ GG-395 filter is used. If the 100 mW/cm² normalized airmass 1.5 direct (AM1.5D) spectrum is required, then a 2-millimeter thick Schott™ GG-4 filter is used.

Depending on which filter is in use, the horizontal slit filter is adjusted in slit width to provide the desired intensity according to a reference cell or balloon standard calibrated in the desired spectral irradiance distribution (i.e., AM0, AM1.5G or AM1.5D).

Lamp Aging and Intensity Reduction

Previous tests have shown that after 100,000 lamp flashes had been registered on the control console flash counter, there was no significant change in the spectral output of the lamps. This number of flashes is equivalent to just under 6 minutes of total operating time if one were to include the 0.5-ms rise time and the 1.0-ms fall time of each lamp flash. The EG&G model FX47C-6.5 lamps are usually replaced after about 100,000 flashes. Replacement lamps have exhibited only minor variations in intensity, spectral irradiance distribution, test-plane uniformity or pulse shape when accurately positioned in the illuminator assembly and operated at the same charge voltage.

The Pulse Network Voltage (PNV) is maintained at a value of 2700 volts to maintain lamp color temperature. Intensity reduction is performed by inserting a horizontal slit filter inside the illuminator assembly in front of the vertical lamps. A smaller slit dimension will cause a proportionally lower intensity to be emitted from the illuminator assembly. The spectral irradiance distribution is not measurably affected because the PNV to the lamps is held constant. The light uniformity at the test plane is also not measurably affected because the slit width has no notable effect on the dispersion of the light upon the 2.1 X 2.1 meter area in the center of the target plane.